

2008

The development of a plastic scintillator for radiotherapy dosimetry

Johnny Estuardo Morales
University of Wollongong

Follow this and additional works at: <https://ro.uow.edu.au/theses>

University of Wollongong

Copyright Warning

You may print or download ONE copy of this document for the purpose of your own research or study. The University does not authorise you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site.

You are reminded of the following: This work is copyright. Apart from any use permitted under the Copyright Act 1968, no part of this work may be reproduced by any process, nor may any other exclusive right be exercised, without the permission of the author. Copyright owners are entitled to take legal action against persons who infringe their copyright. A reproduction of material that is protected by copyright may be a copyright infringement. A court may impose penalties and award damages in relation to offences and infringements relating to copyright material.

Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

Unless otherwise indicated, the views expressed in this thesis are those of the author and do not necessarily represent the views of the University of Wollongong.

Recommended Citation

Morales, Johnny E, The development of a plastic scintillator for radiotherapy dosimetry, MSc-Res thesis, Department of Engineering Physics, University of Wollongong, 2008. <http://ro.uow.edu.au/theses/105>

NOTE

This online version of the thesis may have different page formatting and pagination from the paper copy held in the University of Wollongong Library.

UNIVERSITY OF WOLLONGONG

COPYRIGHT WARNING

You may print or download ONE copy of this document for the purpose of your own research or study. The University does not authorise you to copy, communicate or otherwise make available electronically to any other person any copyright material contained on this site. You are reminded of the following:

Copyright owners are entitled to take legal action against persons who infringe their copyright. A reproduction of material that is protected by copyright may be a copyright infringement. A court may impose penalties and award damages in relation to offences and infringements relating to copyright material. Higher penalties may apply, and higher damages may be awarded, for offences and infringements involving the conversion of material into digital or electronic form.

**THE DEVELOPMENT OF A PLASTIC
SCINTILLATOR FOR
RADIOTHERAPY DOSIMETRY**

A thesis submitted in fulfilment of the
requirements for the award of the degree

Master of Science By Research

from

UNIVERSITY OF WOLLONGONG

by

Johnny Estuardo Morales

BMedPhys(Hons)

Department of Engineering Physics

2008

CERTIFICATION

I, Johnny Estuardo Morales, declare that this thesis, submitted in fulfilment of the requirements for the award of Master of Science, in the Department of Engineering Physics, University of Wollongong, NSW, Australia is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Johnny E. Morales

19th March 2008

TABLE OF CONTENTS

THESIS CERTIFICATION.....	ii
TABLE OF CONTENTS.....	iii
LIST OF TABLES.....	vi
LIST OF FIGURES.....	vii
ABSTRACT.....	x
ACKNOWLEDGEMENTS.....	xi

CHAPTER 1: Introduction: dosimetry in radiotherapy.....	1
1.1 Introduction.....	1
1.2 Objectives and Brief Description of Current research.....	1
1.2.1 Objectives.....	1
1.2.2 Brief Description	2
1.3 Thesis Outline	2
1.4 Existing Dosimetry in Radiotherapy.....	4
1.4.1 Ionisation Chambers.....	4
1.4.1.1 Cylindrical Ionisation Chambers.....	4
1.4.1.2 Parallel Plate Ionisation Chambers.....	6
1.4.1.3 Film	8
1.4.1.3.1 Radiographic Emulsions.....	8
1.4.1.3.2 Photographic process	8
1.4.1.4 Luminescent Detectors.....	10
1.4.1.5 Semiconductor Detectors.....	12
1.4.1.5.1 Silicon Diodes.....	12
1.4.1.5.2 MOSFETS.....	13
1.4.1.5.3 Diamond Detectors.....	14
1.5 Plastic Scintillators and Optical Fibres.....	15

CHAPTER 2: Plastic Scintillators and Optical Fibres in Radiotherapy.....	18
2.1 Introduction.....	18
2.2 The Characteristics of scintillators and fibres.....	18
2.2.1 Classification of Scintillator materials.....	18
2.2.2 Physical process in organic scintillators.....	19
2.2.3 Cerenkov Radiation.....	21
2.2.4 Refraction and Total Internal Reflection in Optical Fibres.....	21
2.3 Applications in Radiotherapy.....	23
2.3.1 The Beddar System.....	23
2.3.2 The Meger Wells System.....	25
2.3.3 The Aoyama System.....	25

2.3.4 The Letourneau System.....	26
2.4 Optimal design for fibre system for dosimetry with linacs.....	27
2.4.1 Single channel vs dual channel.....	27
2.4.2 Choice of scintillator.....	27
3.4.3 Matching to fibre.....	28
3.4.4 Match to detector.....	28
2.5 Subsequent developments in plastic scintillation dosimetry.....	30
CHAPTER 3: Coupling Techniques: Optical Fibre to Photodiode, Scintillator to Optical Fibre.....	33
3.1 Introduction.....	33
3.2 Design 1.....	34
3.2.1 Silica Optical Fibre.....	34
3.2.2 Photodiode.....	34
3.2.3 Epotek Epoxy.....	35
3.2.4 Ultra Violet light source.....	35
3.2.5 Joint Additional Strengthening.....	35
3.2.6 Surface Polishing.....	36
3.2.7 Coupling of Photodiode to Silica Optical Fibre.....	36
3.2.8 Ultraviolet Curing	38
3.3 Design 2.....	40
3.3.1 Optical Fibre.....	41
3.3.2 Photodiode SFH250.....	41
3.3.3 Plastic Scintillator.....	42
3.4 Attachment of Plastic Scintillator to Optical Fibre.....	42
3.5 Plastic Scintillator Polishing	43
CHAPTER 4: Methodology and Experimental Work.....	45
4.1 Introduction.....	45
4.2 Methods.....	46
4.2.1 Experimental set-up for beam profile measurement in Water using Optical fibre and Plastic scintillator.....	46
4.2.2 Experimental set-up for beam profile measurement in water using commercial detectors: CC04, CC13, PFD and SFD	48
4.3 Results.....	49
4.3.1 Results obtained with Optical fibre and Plastic Scintillator.....	49
4.3.2 Results obtained with other detectors: CC04, CC13, PFD and SFD.....	51
4.4 Discussion of Results.....	53
4.4.1 Justification for the Gamma Evaluation Method.....	53
4.4.2 Description of the Gamma Evaluation method.....	54
4.4.3 Analysis of Plastic scintillator results using the Gamma Evaluation method.....	57

4.4.3.1 Plastic Scintillator versus CC13	57
4.4.3.2 Plastic Scintillator versus CC04.....	59
4.4.3.3 Plastic Scintillator versus PFD.....	60
4.4.3.4 Plastic Scintillator versus SFD.....	61
CHAPTER 5: Conclusion.....	62
5.1 Technique to couple optical fibre to photodiode for Design 1.....	62
5.2 Coupling of optical fibre to photodiode for Design 2.....	62
5.3 Technique to couple plastic scintillator to optical fibre.....	62
5.4 Subtraction of Cerenkov signal.....	63
5.6 Gamma evaluation analysis.....	63
5.7 Future Work on Plastic Scintillation dosimetry in radiotherapy.....	64
References.....	66

LIST OF TABLES

Table 4.1: Siemens Primus Linear Accelerator specifications for 10x10 cm ² at 100 cm Source to Surface Distance.....	46
Table 4.2: Commercial Detectors Specifications.....	48

LIST OF FIGURES

Figure 1.1: Farmer chamber. Reproduced from The Physics of Radiation Therapy by F.M.Khan.....	5
Figure 1.2: Cross section of an x-ray film. The base is cellulose acetate or a polyester resin, and the emulsion is usually silver bromide suspended in a gelatin matrix. (Reproduced from Medical Imaging Physics by Hendee and Ritenour 2002).....	8
Figure 2.1: Energy levels of a π -electron structure. Reproduced from Radiation Detection and Measurement by F.G. Knoll, 1989.....	19
Figure 2.2: Fluorescence decay as function of time. Reproduced from Introduction to Radiation Detectors and Electronics by Helmuth Spieler, 1998.....	21
Figure 2.3: Principle of Refraction and Total Internal Reflection at boundary between medium 1 and medium 2.....	22
Figure 2.4: Total Internal Reflection in an Optical Fibre.....	23
Figure 2.5: Plastic scintillator system as published by S. Beddar in 1992.....	24
Figure 2.6 Plastic scintillator system as published by Meger-Wells in 1994.....	25
Figure 2.7 Plastic scintillator system published by T. Aoyama in 1995 and 1996.....	26
Figure 2.8 Plastic scintillator system published by D. Letourneau in 1999.....	27
Figure 2.9 Schematic drawing of an optimal design. In an optimal design 100% of light produced by plastic scintillator would be transmitted to photodiode.....	30
Figure 3.1 Schematic drawing representing the assembly of coupling photodiode to silica fibre.....	35
Figure 3.2 Customised assembling jig. Jig was used for coupling optical fibre to photodiode.....	37
Figure 3.3 Silica Alignment of silica optical fibre on photodiode prior to ultraviolet curing. Epotek epoxy was poured between the silica optical fibre and the photodiode.....	39
Figure 3.4 Violet curing. Purple colour shows ultraviolet beam on epotek epoxy.....	39

Figure 3.5 Picture of Design 1. Photodiode contacts were soldered on BNC triaxial connector. Black shrink plastic was used to seal joint from environmental light.....	40
Figure 3.6 Spectral sensitivity of SFH250 photodiode.....	41
Figure 3.7 Attachment of Plastic Scintillator to Optical fibre.....	43
Figure 4.1 Wellhöfer water tank place under Siemens linac.....	45
Figure 4.2 Drawing showing the direction of scanning for 6MV photon profile.....	47
Figure 4.3 Readings measured by optical fibre with no plastic scintillator.....	49
Figure 4.4 Readings measured by optical fibre when plastic scintillator BCF60 was attached to it.....	50
Figure 4.5 Plastic scintillator signal. Signal was extracted from readings from figures 4.3 and 4.4.....	50
Figure 4.6 6MV photon beam profile measured by ion chamber CC04 at 1.5cm depth.....	51
Figure 4.7 6MV photon beam profile measured by ion chamber CC13 at 1.5cm depth....	51
Figure 4.8 6MV photon beam profile measured by commercial diode PFD.....	52
Figure 4.9 6MV photon beam profile measured by commercial stereotactic diode SFD at 1.5cm depth.....	52
Figure 4.10 Gamma method in two dimension. Reproduced from Low et al.....	54
Figure 4.11 Gamma function. Reproduced from Low et al.....	56
Figure 4.12 Equation of an ellipsoid surface. Reproduced from Low et al.....	56
Figure 4.13 Gamma function. Reproduced from Low et al.....	57
Figure 4.14 Gamma function evaluation for CC13 and Plastic Scintillator.....	58
Figure 4.15 Gamma evaluation function for CC04 and Plastic Scintillator.....	59
Figure 4.16 Gamma Evaluation function for PFD and plastic scintillator.....	60

Figure 4.17 Gamma evaluation function for SFD and plastic
scintillator..... 61

ABSTRACT

A plastic scintillator detector was developed and tested in a 6MV photon beam. The detector comprised a BCF60 plastic scintillator, Polymethyl-Methacrylate Resin optical fibre and photodiode SFH250. The detector was used to measure an inplane profile for the photon beam at a depth of 1.5 cm for a field size of $10 \times 10 \text{ cm}^2$ at 100 cm SSD. The photon beam was delivered by a Siemens linear accelerator. A comparison was made with the results obtained by cylindrical chambers CC04 and CC13, commercial diode PFD and a stereotactic diode SFD, all from the manufacturer IBA-Wellhöfer. An analysis was performed using the Gamma Evaluation method and the agreement was acceptable for a criterion of Distance To Agreement = 2 mm and Dose Difference = 2%.

ACKNOWLEDGMENTS

I would like to acknowledge the help I have received from my main supervisor Associate Professor Bill Zealey from the Department of Engineering Physics at the University of Wollongong, NSW, Australia. He has given me guidance and advice on the project and I am very thankful to him. His final push for completion helped me to get over the line. Thanks a lot Bill.

I also acknowledge the assistance I received from Mr. Nigel Freeman, Chief Physicist at St Vincent's Hospital in Sydney, Australia while I was employed by him and during the measurements presented in this thesis. Nigel's vision and sound advice are greatly appreciated.

I would like to thank Dr. Mamoon Haque, Senior Physicist at Royal Prince Alfred Hospital in Sydney, who provided plenty of advice and positive criticism. His valuable advice was tremendous. And I appreciate his promptness and readiness to assist. His higher degree experience and his medical physics experience were extremely valuable.

I would like to acknowledge Dr Sue Law from The University of Sydney for her assistance in coupling the Silica Fibre to the photodiode.

I also would like to acknowledge Dr Anatoly Rozenfeld from the University of Wollongong for his initial encouragement at the beginning of this project.

Finally, I would like to acknowledge my family for their endless support and above all for their infinite encouragement. My family was always there for me at all times and their genuine support has always been a source of motivation for this project, for my personal life and for my professional development in my chosen career as a medical physicist.